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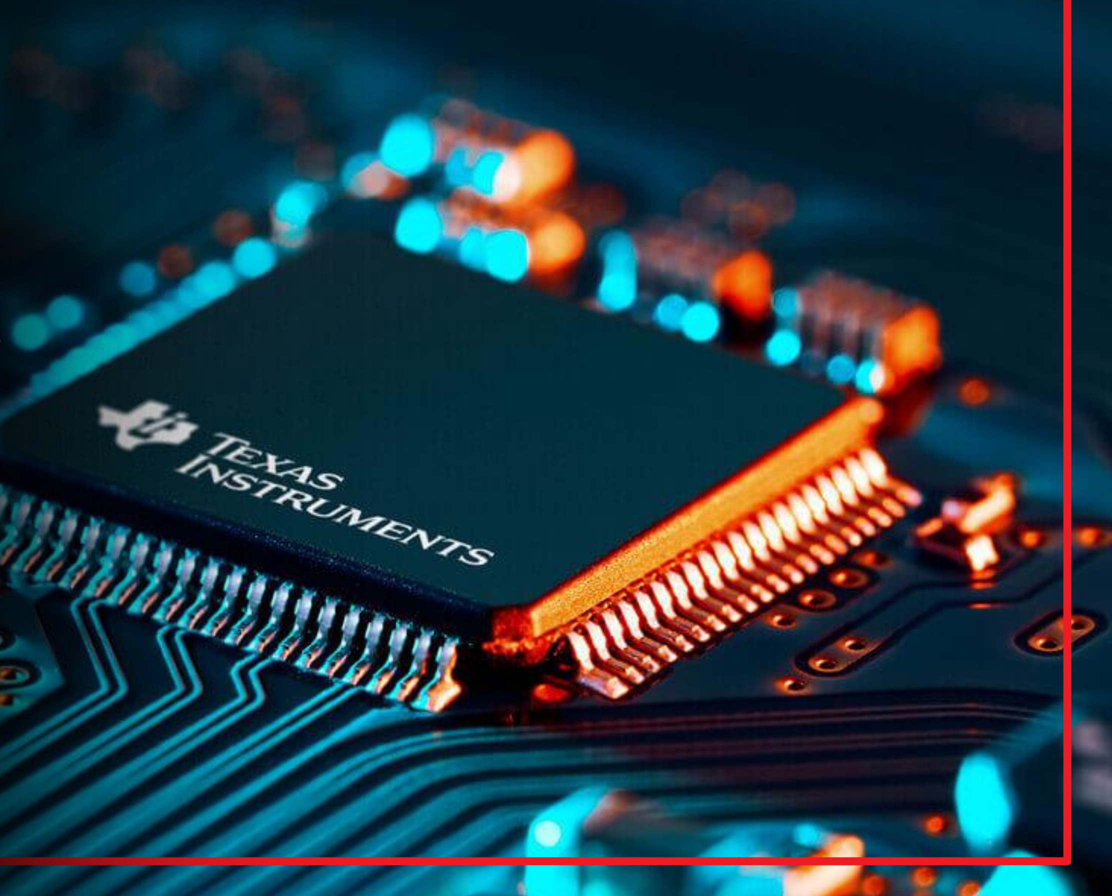
2024 Embedded Seminar

Highly-accurate, AI-enabled fault monitoring for real-time control systems



Jiaxin Teng

Systems Engineer

Agenda

- Why Fault Detection for Motor and Arc?
- Benefits AI vs Traditional Method
- Edge-AI vs Cloud-Based AI
- AI Model and Performance
- TI AI Solutions and Toolchains

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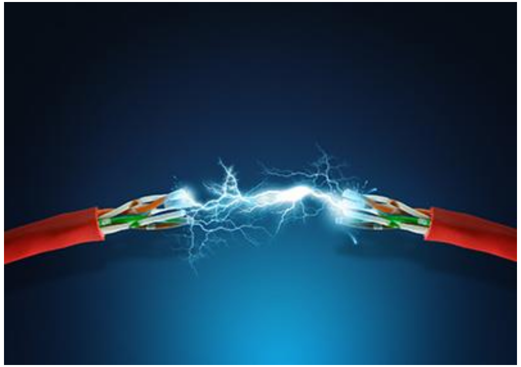
Importance of Motor/Arc Fault Detection

- Motor and its drive are widely applied in modern society, such as manufacture, EV, robotics, etc.. Early motor fault detections through its drive are vital to:
  - Reduce down time
  - Lower repair cost
  - Improve safety
- In the evolving landscape of energy systems, e.g., photovoltaic grids, charging stations, home inverters, where AC and DC coexist, the threat of DC series arc fault becomes pronounced. Effective DC arc fault detection can largely help avoid:
  - Start formidable fire hazard as wires off or contacts break
  - Damage property
  - Endanger people's lives



Benefits of AI vs Traditional Method

	Traditional analytical method	AI-based method
Classification accuracy	• Bearing[1]: 60~80%; typically 1 fault per model • Arc[2]: <80%	• >98%[1][2]; supports multi-class per model
Noise susceptibility	• Sensitive to load condition changes • Higher false alarm rate when noise and signal have similar pattern	• Robust against noise and faults due to effective NN feature extraction
Adaptability to new condition	• Requires manual parameter re-tuning	• **Continuous learning and update model parameter**
Detection algorithm	• Requires domain expertise • Methods: signal analysis, modeling	• Data driven • Methods: (1) FE + CNN, (2) RAW + CNN
Solution development difficulty	• Requires domain experts to determine fault types • Rely on root cause analysis	• Less domain expertise required • Rely on data collection and training

1. *Based on Fault Diagnosis and Fault-Tolerant Control of PMSM Drives State of Art and Future Challenges, 2022*
2. *Based on "STM32 AI for AFCI in Solar Power Inverter" reference*

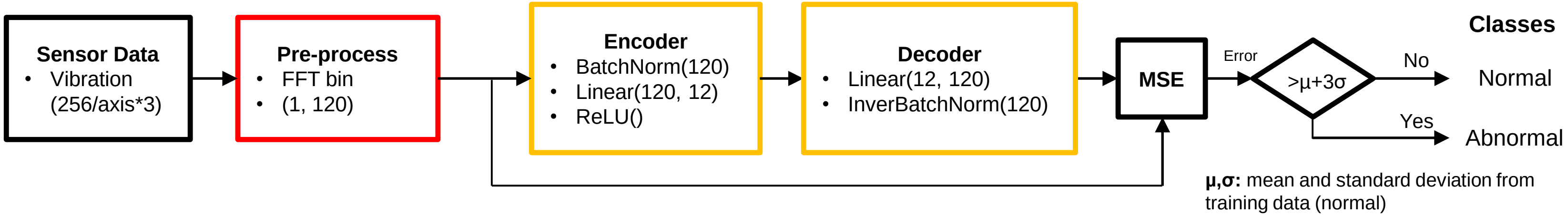
Edge-AI vs Cloud-Based AI

	Edge-AI ✓	Cloud-Based AI
Location of Data Processing	All data processing is done locally on device	Data is sent from device to cloud servers where processing occurs
Computing Power	Comes with a boundary on the processing capacity due to the limitation of device's size	Greater computational capabilities and storage capabilities
Privacy and Security	Enhanced privacy	Potential privacy risks
Dependency on the Internet	Operates independently of internet connectivity	Requires a strong and continuous internet connection
Latency	Reduced latency, crucial for immediate responses needed in applications like real-time health monitoring	**Can experience delays**

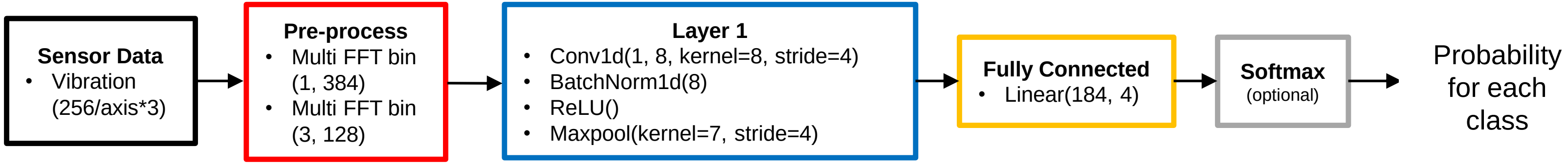
Reference: 1. Medium article "On Device AI: What It Is and How It Works?"
2. IBM Topics Edge AI

AI Models Studied for Motor Fault Detection

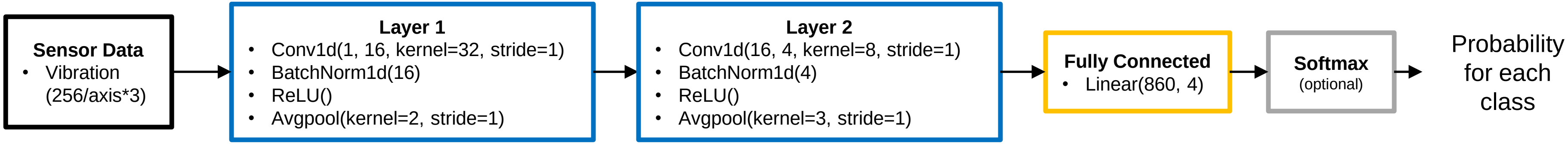
Autoencoder: (1) AE1 w/ on-chip learning, (2) convAE



CNN1: pre-process + NN

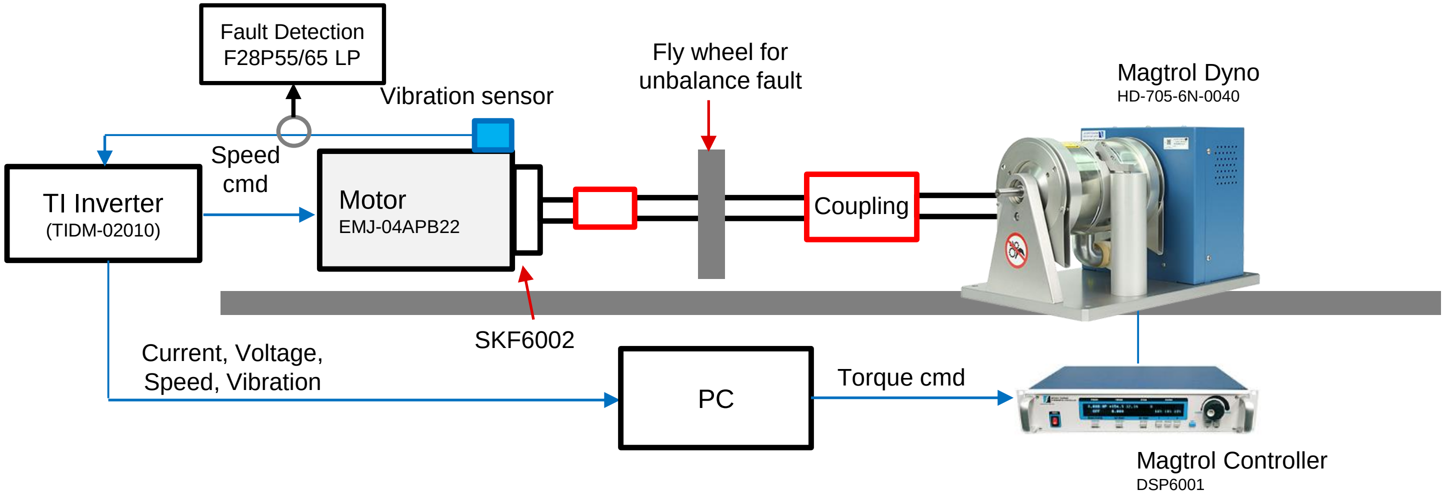


CNN2: raw + NN



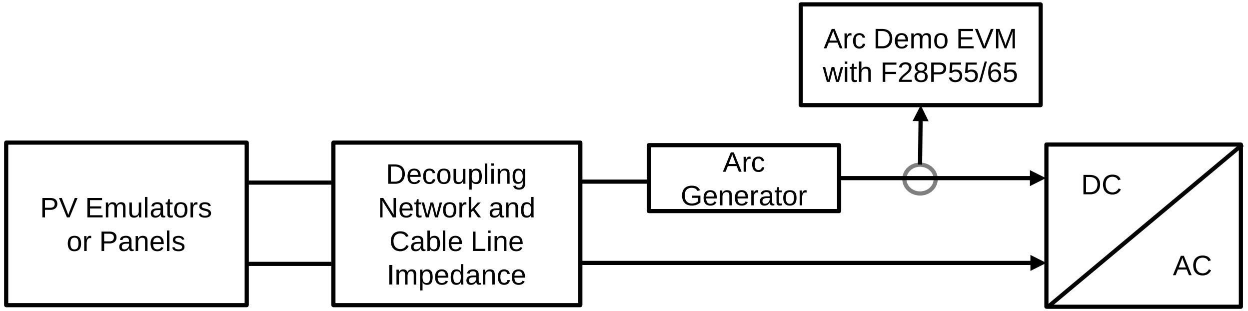
: target with on-chip learning

Model Performance in Motor Fault Detection



Model	Param	MAC	Train	FE	Configuration	Input (ChxFLxHL)	Output	Acc (%)
CNN1	830	11392	FP	Multi FFT bin	256/ax, 3ax, 8frames, 4kHz	1x384x1	4	97.77
CNN1	832	11392	QAT,8b	Multi FFT bin	256/ax, 3ax, 8frames, 4kHz	1x384x1	4	97.45
CNN1	452	8704	QAT,8b	Multi FFT bin	256/ax, 3ax, 8frames, 4kHz	3x128x1	4	99.33
CNN2	5561	485532	QAT,8b	CNN	256/ax, 3ax, 1frame, 4kHz	3x256x1	4	98.88

Model Performance in Arc Fault Detection



	Number of Parameters	Frame Length	Features	Test Set Accuracy
CNN Model (CNN3_16)	2712	1024 samples	512	100%
CNN Model (CNN3_12)	1652	1024 samples	512	100%
CNN Model (CNN3_8)	848	1024 samples	512	100%
CNN Model (CNN3_4)	296	1024 samples	512	100%

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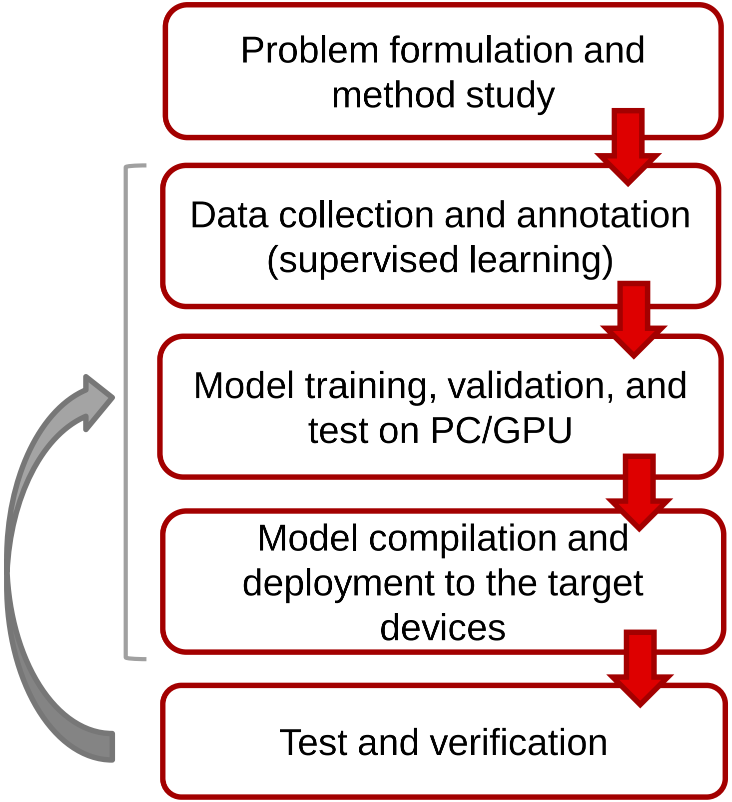
General Steps of Edge AI/ML Development



Example problems studied by TI:
- *Motor bearing fault detection and classification*
- *Fan imbalance detection and classification*
- *Arc fault detection*

Solution provided by TI:
- *Data collection GUI for motor and arc*
- *Combined GUI in Model Composer*

Solution provided by TI:
- *Pre-studied models with Model Maker, Model Composer*

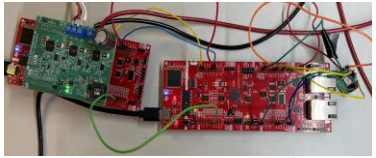
Customized solution:
- *Model training with libs in Python, Tensorflow, Pytorch*

Solution provided by TI:
- *Compilers to convert the AI model into C code optimized for C2000*
- *User guide and example project in device deployment*

May need to repeat the previous steps to achieve the best results in the actual working environment

Solution Development Flow with TI Toolchain

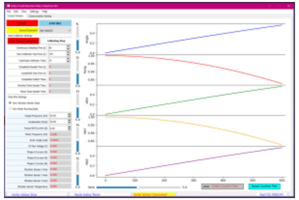
Evaluation platforms

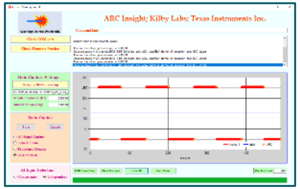


Available EVMs + LPs as fault detection EVMs

- Data acquisition, logging, and labeling
- Fault detection

Training data collection

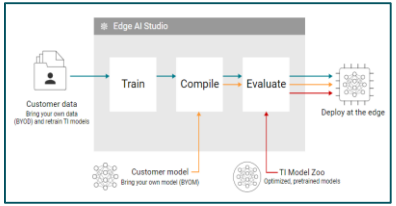




Data acquisition tool

- Sensor data acquisition
- Communication between PC and target LP

Model training and compilation



Online Tool – **Edge AI Studio**

- Train / validate / test customer data with TI optimized models
- Compile AI models

Offline Tool – **Command-line Model Maker**

- Custom model development
- Offline data training

Model integration with application

C2000Ware DigitalPower SDK
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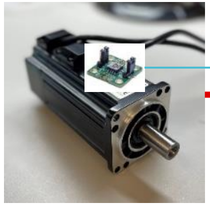
Code deploy at the edge on C2000

- CCS, API lib, SDK

Demo Description and Highlights

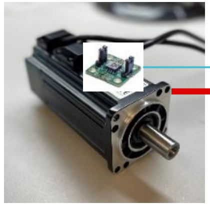
Motor 1 with normal bearing



Vibration signal of motor 1

Connection to control motor 1

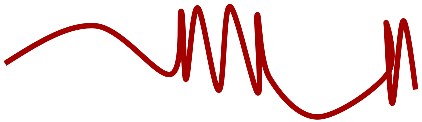
Motor 2 with faulty bearing



Vibration signal of motor 2

Connection to control motor 2

Vibration sensor data on DAC output



GPIO to indicate fault detection

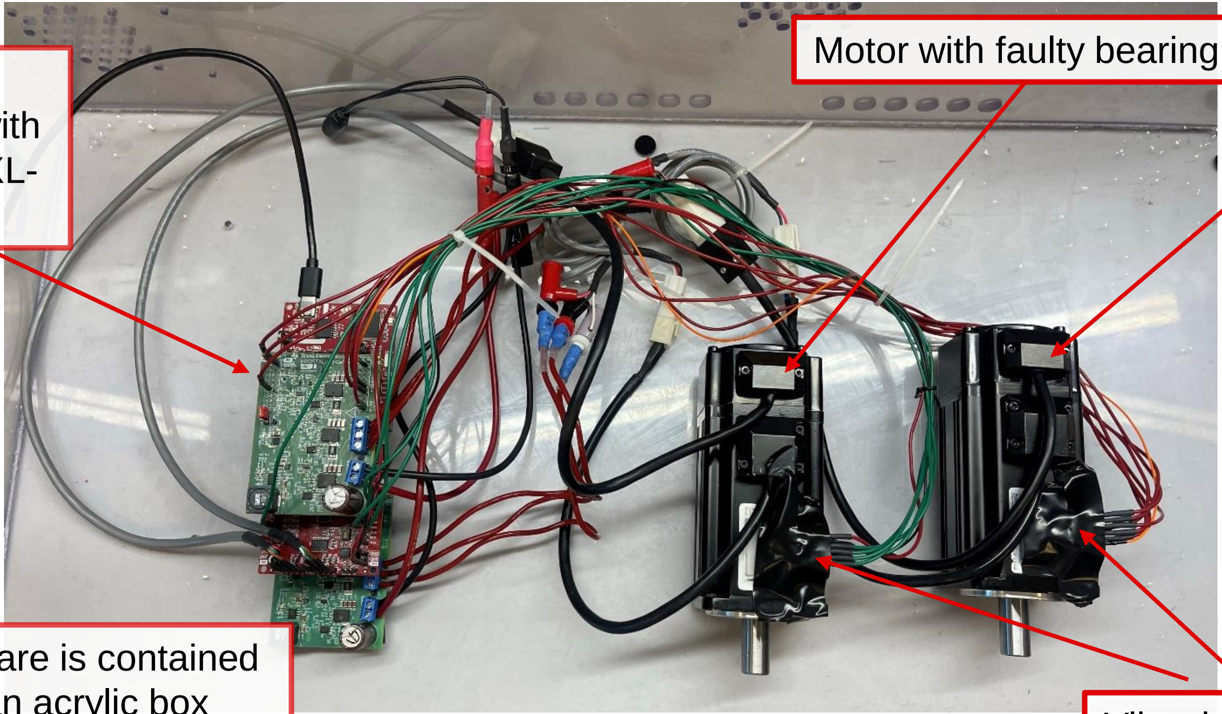
good

bad

Demo Highlights

- CNN model running on the AI NPU (Neural-network Processing Unit) for fast and accurate fault detection
- Vibration sensor signals from the two motors are switched to emulate real-time fault occurrence
- Control of two motors via eQEP sensor-based FOC and fault detection with a single MCU
- Low memory usage and detection latency
- Edge AI full development tool chain via EdgeAI Studio

Demo setup



F28P55x Launchpad with two BOOSTXL-3PHGANINV

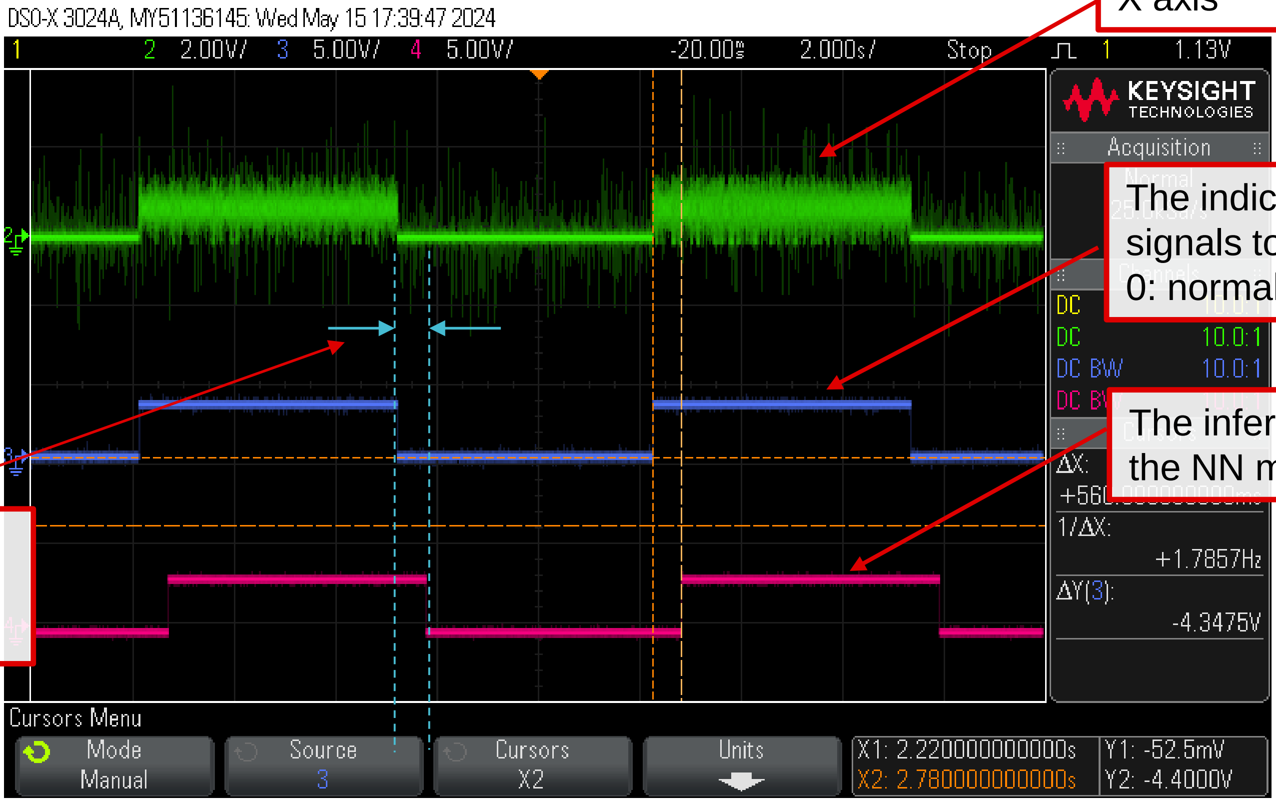
Motor with faulty bearing

Motor with normal bearing

All the hardware is contained and fixed in an acrylic box

Vibration sensor

Display on Oscilloscope



Actual vibration signal on X axis

The indicator on current signals to the NN model, 0: normal 1: faulty

The inference results of the NN model

1.06 mS of fault detection latency

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